

Dissolved organic carbon and nitrogen in precipitation, throughfall and stemflow from *Schima superba* and *Cunninghamia lanceolata* plantations in subtropical China

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Abstract: Despite growing attention to the role of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) in forest nutrient cycling, their monthly concentration dynamics in forest ecosystems, especially in subtropical forests only were little known. The goal of this study is to measure the concentrations and monthly dynamics of DOC and DON in precipitation, throughfall and stemflow for two plantations of *Schima superba* (SS) and Chinese fir (*Cunninghamia lanceolata*, CF) in Jianou, Fujian, China. Samples of precipitation, throughfall and stemflow were collected on a rain event base from January 2002 to December 2002. Upon collection, all water samples were analyzed for DOC, NO_3^- -N, NH_4^+ -N and total dissolved N (TDN). DON was calculated by subtracting NO_3^- -N and NH_4^+ -N from TDN. The results showed that the precipitation had a mean DOC concentration of $1.7 \text{ mg} \cdot \text{L}^{-1}$ and DON concentration of $0.13 \text{ mg} \cdot \text{L}^{-1}$. The mean DOC and DON concentrations in throughfall were 11.2 and $0.24 \text{ mg} \cdot \text{L}^{-1}$ in the SS and 10.3 and $0.19 \text{ mg} \cdot \text{L}^{-1}$ in the CF respectively. Stemflow DOC and DON concentrations in the CF (19.1 and $0.66 \text{ mg} \cdot \text{L}^{-1}$ respectively) were significantly higher than those in the SS (17.6 and $0.48 \text{ mg} \cdot \text{L}^{-1}$ respectively). No clear monthly variation in precipitation DOC concentration was found in our study, while DON concentration in precipitation tended to be higher in summer or autumn. The monthly variations of DON concentrations were very similar in throughfall and stemflow at both forests, showing an increase at the beginning of the rainy season in March. In contrast, monthly changes of the DOC concentrations in throughfall of the SS and CF were different to those in stemflow. Throughfall DOC concentrations were higher from February to April, while relatively higher DOC concentrations in stemflow were found during September–November period.

Keywords: Dissolved organic carbon (DOC); Dissolved organic nitrogen (DON); Precipitation; Throughfall; Stemflow; *Schima superba*; *Cunninghamia lanceolata*; Plantation

CLC number: S712.5; S791.27

Document Code: A

Article ID: 1007-662X(2005)01-0019-04

Introduction

Dissolved organic carbon (DOC) and nitrogen (DON) are thought to contribute significantly to the C and N cycle in terrestrial ecosystems, to soil formation and to pollutant transport. Several investigations have sought to understand the nature and dynamics of DOC (Cronan *et al.* 1985; McDowell *et al.* 1988; Neff *et al.* 2001), but there were only few reports about DON in ecosystems. In some ecosystems, dissolved organic N represents the major form of nitrogen in solution (Hedin *et al.* 1995; Stuarnes *et al.* 1995; Currie *et al.* 1996), and DON losses may occur despite overall ecosystem demand for N (Hedin *et al.* 1995; McHale *et al.* 2000). Further, most present studies focus on a single element at a time, and few have evaluated on the relative changes of C and N in dissolved organic matter (DOM) with solution movement through ecosystems (Qualls *et al.* 1991).

Recently, the measurements of DOC and DON concentrations in throughfall and stemflow have indicated that interception by the canopies and stems of trees can greatly alter DOC and DON concentrations in precipitation among different species of trees (Inagaki *et al.* 1995; Currie *et al.* 1996) and seasonally (McDow-

ell *et al.* 1988). Besides rainfall volume, leaching of compounds from leaves and stems is considered to be the primary factors influencing variability in carbon and nitrogen concentrations among solutions. Although the dynamics of DOC and DON have been addressed in several temperate and tropical forests (McDowell *et al.* 1988; Inagaki *et al.* 1995; Currie *et al.* 1996; Michalzik *et al.* 1999; Michalzik *et al.* 2001), little is known about DOC and DON in forests of southern China, an area of the most important world subtropical forests. The objective of this study is, thus, to determine monthly changes of DOC and DON concentrations in precipitation, throughfall and stemflow of two plantation forests of *Schima superba* (SS) and Chinese fir (*Cunninghamia lanceolata*, CF) in northern Fujian.

Study area

The study was carried out at the Long-Term Ecological Research site in Jianou, Fujian ($27^{\circ}20'N$, $118^{\circ}57'E$). It borders Jiufeng Mountain on the southeast, with Wuyi Mountain on the northwest. The region has a middle sub-tropical monsoonal climate, with a mean annual temperature of 18.7°C and a relative humidity of 80%. The mean annual precipitation is 1664 mm, mainly occurs from March to August (Fig. 1). Mean annual evapotranspiration is 1466 mm. The parent material of the soil is granite and soils are classified as red soils (humic Planosols in FAO system). Thickness of the soil exceeds 1.0 m.

Two adjacent stands consisting of *Schima superba* (SS) and Chinese fir (*Cunninghamia lanceolata*, CF) plantations were investigated. Both of SS and CF were derived from a shaw. The shaw was clear-cut and planted with *S. superba* and Chinese fir

Foundation item: This study was supported by the Teaching and Research Award program for MOE P. R. C. (TRAPOYT).

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Received date: 2004-10-27

Responsible editor: Zhu Hong

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15 years ago. Selected stand characteristics and some properties of the surface soil (0-20cm) of the two stands are described in Table 1.

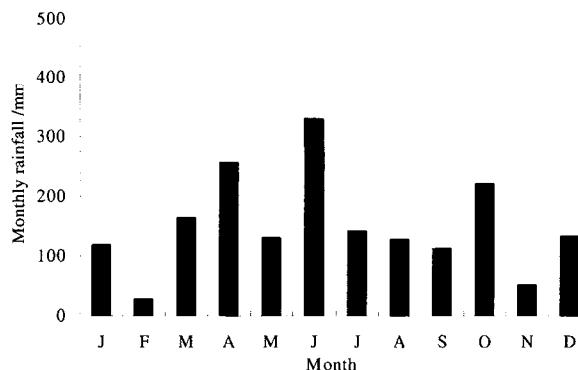


Fig. 1 Rainfall patterns for the study area in 2002

Table 1. Forest characteristics and soil properties of the study sites

Parameters	Forest type	
	<i>Schima superba</i>	Chinese fir
Forest characteristics		
Stand age (year)	15	15
Mean tree height (m)	9	11
Mean tree diameter at breast height (cm)	8.9	10.6
Stand density (stem ha ⁻¹)	1700	2390
Soil properties (top 0-20cm depth)		
Bulk density (g cm ⁻³)	1.06	1.07
Organic matter (g·kg ⁻¹)	29.9	27.9
Total N (g·kg ⁻¹)	0.938	0.808
Total P (g·kg ⁻¹)	0.622	0.401
Hydrolyzable N (mg·kg ⁻¹)	94.3	110.3
Available P (mg·kg ⁻¹)	4.84	4.52

Materials and methods

Water sample collection and analysis

Samples of precipitation, throughfall and stemflow were collected on a rain event base from January 2002 to December 2002. Bulk precipitation was gathered by using 3 rain collectors of 314 cm² in an open area about 100 m away from the site, where there was a meteorology station.

Each throughfall collector consisted of two 20-cm diameter funnels was mounted about 1 m above the ground and arranged in a crossed shape with an upright projection area of 1.8 m²; the funnels were connected to a 10-L sampling tank with polyethylene tubes. In order to keep out leaves, small branches, and insects, 3-mm mesh plastic screen was used to cover the funnels. Five such throughfall collectors were installed randomly in each stand.

The stemflow collector was consisted of tygon tubing (3.8 cm outer and 3.0 cm inner diameters) which was longitudinally split. The tubing was wrapped on a downward spiral around the tree bole, fastened with stainless steel staples and sealed to the bark with silica gel. The lower and unsplit end of the tubing was inserted into a hole in the lid of a 10-L plastic sampling tank. Nine standard trees of a stand were chosen to collect stemflow in both stands.

Upon collection, all water samples were filtered through Gelman GN-6 grid with 0.45-μm membrane filters and stored at 4°C until analyzed for DOC, NO₃⁻-N, NH₄⁺-N and total dissolved N

(TDN). DON was calculated by subtracting NO₃⁻-N and NH₄⁺-N from TDN. The DOC concentration of each filtered water sample was determined by using a TOC analyzer with high temperature combustion system (Elementar Analysensysteme GmbH, Germany). NO₃⁻-N was determined colorimetrically by using an autoanalyser and NH₄⁺-N was analyzed by the indophenol blue method (DSTMF 1992), while TDN was determined by UV-persulphate digestion (Ameel *et al.* 1993). Analyses were carried out in triplicate.

Statistical analyses

Duncan's multiple range test was used for mean comparison if the results of the *F*-test were significant at the 5% level.

Results

Concentrations of DOC and DON

The mean DOC and DON concentrations in both forests increased in the following order: bulk precipitation < throughfall < stemflow (Table 2). DOC and DON concentrations in precipitation averaged at 1.7 and 0.13 mg·L⁻¹, respectively. The DOC concentrations in throughfall of the SS and CF were 6.6 times and 6.1 times as much as that in precipitation, respectively. Concentrations of DOC in stemflow of both forests were significantly higher than that in precipitation (*p* < 0.05). Compared with precipitation, throughfall and stemflow in the two forests also had significantly higher DON concentrations (*p* < 0.05). In the SS, concentrations of DOC and DON in throughfall were both higher than those of the CF. In contrast, the DOC and DON concentrations in stemflow in the SS were lower than those in the CF.

Table 2. Average solution concentration (mean±SE) of DOC and DON in two forest types (mg·L⁻¹)

Parameters	DOC	DON
Bulk precipitation	1.7±0.2d	0.13±0.02d
<i>Schima superba</i> forest		
Throughfall	11.2±1.5c	0.24±0.03c
Stemflow	17.6±2.6b	0.48±0.06b
Chinese fir forest		
Throughfall	10.3±1.3c	0.19±0.03c
Stemflow	19.1±3.1a	0.66±0.09a

Notes: Means for each measurement at DOC and DON concentrations followed by the different letter on the same column are significantly different at the 5% level using Duncan-Waller multiple range test.

Monthly variations in concentrations of DOC and DON

Concentrations of DOC and DON in throughfall and stemflow in every month were generally higher than those in precipitation (Fig. 2-4). In precipitation, DOC concentration did not show a distinct monthly variation (Fig. 2), however, there was an increasing trend of DOC concentrations during drier periods in autumn and winter. The DON concentration in precipitation tended to be relatively lower during March to May than in other months. In the SS and CF, the monthly variations of DON concentrations were very similar in throughfall and stemflow, showing an increase at the beginning of the rainy season in March. In contrast to DON, the monthly variations of the DOC concentrations were different in throughfall and in stemflow (Fig. 3 and 4); The DOC concentrations in throughfall were higher from February to April during the year, while in stemflow, relatively higher DOC concentrations were found during September to November in the year.

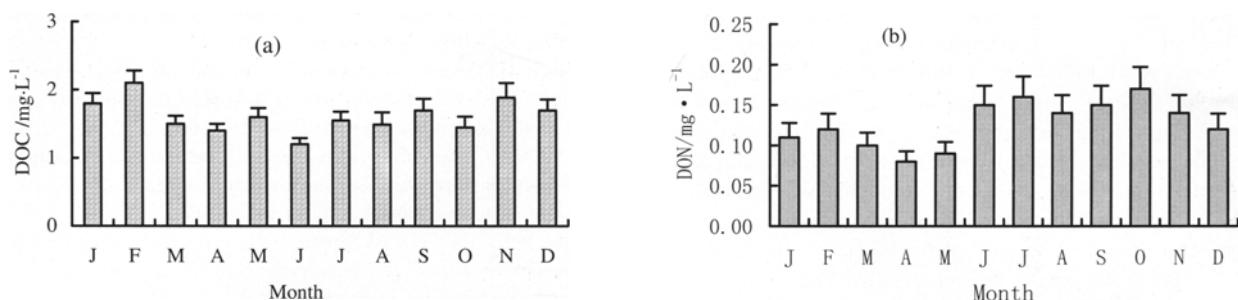
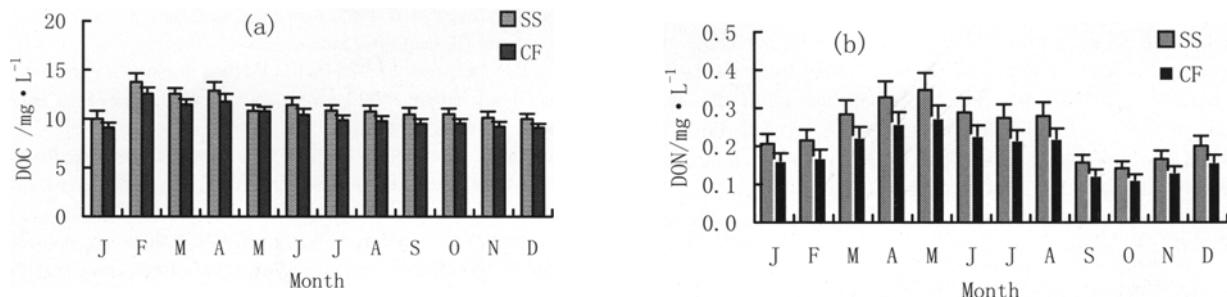
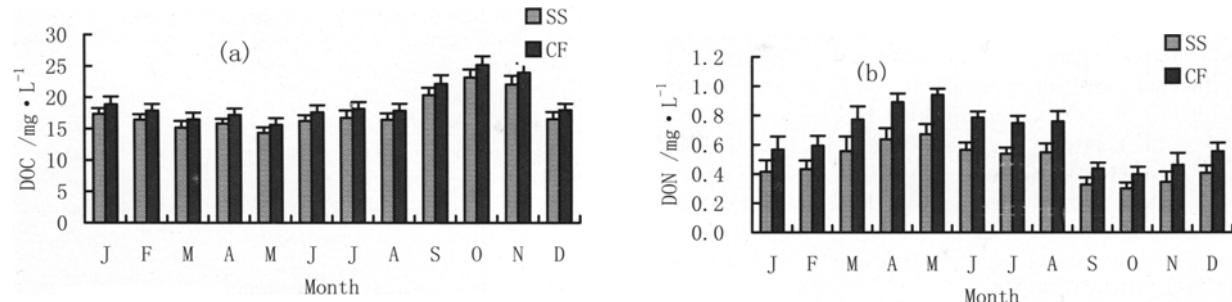


Fig. 2 Monthly variation in concentrations of DOC (a) and DON (b) in precipitation

Fig. 3 Monthly variation in concentrations of DOC (a) and DON (b) in throughfall in *Schima superba* (SS) and Chinese fir (CF) forestsFig. 4 Monthly variation in concentrations of DOC (a) and DON (b) in stemflow in *Schima superba* (SS) and Chinese fir (CF) forests

Discussion

Concentrations of DOC and DON

Precipitation is a significant source of DOC and DON for subtropical forest ecology (Likens *et al.* 1983). In this study, the mean concentrations of DOC and DON in precipitation were comparable to other studies (Currie *et al.* 1996; Michalzik *et al.* 1999; Solinger *et al.* 2001). For example, Solinger *et al.* (2001) found mean concentrations of DOC and DON for 2.0 mg·L⁻¹ and 0.2 mg·L⁻¹ in rainfall above a deciduous forest in northern Bavaria, Germany. Currie *et al.* (1996) reported DOC concentrations of 1.8 mg·L⁻¹ in precipitation in a hardwood forest in Massachusetts, USA. But the concentration of DOC in precipitation in our study was much lower relative to the coniferous forest (2.9 mg·L⁻¹) in Wisconsin, USA (Quideau *et al.* 1997). Overall, our values of DOC and DON concentrations entering the ecosystems by precipitation were close to those reported for many temperate forests (average concentrations of DOC and DON for 1.8 mg·L⁻¹, 0.17 mg·L⁻¹), (Michalzik *et al.* 2001).

The mean DOC and DON concentrations in throughfall for both forests (10.8 mg·L⁻¹ and 0.22 mg·L⁻¹) were lower at con-

centrations range in throughfall of temperate forests (DOC concentrations for 3–35 mg·L⁻¹; DON concentrations for 0.24–1.11 mg·L⁻¹), (Michalzik *et al.* 2001), but DOC and DON concentrations in throughfall in this study were close to mean DOC concentration in throughfall of a hardwood forest in South Sweden (9.9 mg·L⁻¹; Bergkvist *et al.* 1992) and to mean DON concentration in throughfall of a deciduous forest in southern Appalachians, North Carolina (0.25 mg·L⁻¹; Qualls *et al.* 1991). Further, dissolution of soluble organic material deposited on the surface of the plants, soluble animal or microbially-derived organic material in the canopy, and leaching of leaves or needles may cause significantly higher DOC and DON concentrations in throughfall than those in precipitation (Ciglasch *et al.* 2004).

The differences between DOC and DON concentrations in throughfall for the two forests were attributable to the different structure of the vegetation canopy. The SS canopy covered a higher surface area than that of the CF. Consequently, the area of water contacting with the plant surfaces through the SS canopy were more than that through the CF canopy. This resulted in a stronger increase in DOC concentrations in throughfall of SS than those of CF.

The concentrations of DOC and DON in stemflow at the study sites were lower than mean DOC and DON concentrations in the stemflow of forests in temperate and cold climates ($23\text{--}356 \text{ mg}\cdot\text{L}^{-1}$ and $0.81\text{--}1.80 \text{ mg}\cdot\text{L}^{-1}$; Hinton *et al.* 1998), probably because of different forest structure and climatic conditions. Frangi & Lugo (1985) reported mean DOC concentrations of $9.2 \text{ mg}\cdot\text{L}^{-1}$ in stemflow of a subtropical Puerto Rican palm forest being much less than the DOC concentrations in the SS and CF. This is probably attributable to a pronounced dilution of the Puerto Rican stemflow because of the higher annual rainfall of 3725 mm (vs. 1664 mm at the study sites). The strong enrichment of DOC and DON in stemflow, compared with that in throughfall, particularly in CF, indicated that organic material was leached from the trunks. In addition, the two forests in the present study had similar mean tree height. Moreover, stand age of the CF and SS are same (Table 1). Thus the higher DOC and DON concentrations in stemflow of the CF than those of the SS were mainly related to different bark morphology of the trees (Inagaki *et al.* 1995). Chinese fir has a multi-layered rough fibrous bark which could retain precipitation longer time than single-layered bark thus leaching more DOC and DON. The causes of the variations in these concentrations are complex and warrants further study.

Monthly changes of DOC and DON concentrations

The monthly changes of DON concentrations in precipitation in our study are similar to the findings by Michalzik & Matzner (1999) and Michalzik *et al.* (2001) who found higher DON concentration in precipitation usually occur in late summer or autumn. But this is still open to speculation as to why. Further, concentrations of DOC in precipitation had been observed to decrease in the course of the rainy months (Fig. 2). Similarly, Hoffman *et al.* (1980) and Andreae *et al.* (1990) also reported this trend. Higher DOC concentrations at lower rainfall volumes may be attributable to a concentration effect or to the deposition of dust containing soluble organic matter that is favored by dry conditions (Ciglasch *et al.* 2004).

Higher DOC and DON concentrations in throughfall occurred at the beginning of the rainy season (Fig. 3) because soluble organic material accumulated during the dry season was washed from the plants (Stadler *et al.* 1998). The accumulated material probably resulted from deposited dust and degraded biological material. During the first rain events after the dry season, usually in March, the DON concentrations in stemflow of both forests also increased. Thus, there was a similar initial flush as for throughfall. In this study, the monthly variation in DOC concentrations in stemflow is different from other studies (Liu *et al.* 2003; Ciglasch *et al.* 2004), where the maximum DOC concentrations in the spring/summer has been demonstrated. These short-term and monthly variations (only 1 year) in our study appear difficult to the assessment of the primary factors influencing variability of DOC and DON concentrations, thus, indicating the need for a long-term and intensive sampling program.

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